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Design Construction Analysis Feedback

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CEMP-C

Subject: Air Entrainment of Concrete

Applicability: Information

Reference: CEGS 03300, Structural Concrete
CECW 03301, Structural Concrete
CECW 03305, Mass Concrete
ASTM C 231, Air Content of Freshly Mixed Concrete by the Pressure Method
ASTM C 173, Air Content of Freshly Mixed Concrete by the Volumetric Method
ASTM C 138, Air Content of Freshly Mixed Concrete by the Gravimetric Method

1. Air-entrainment is the inclusion during the mixing process of millions of closely spaced air bubbles of near microscopic size. These bubbles are produced by adding a small amount of an air entraining agent, of which many quality ones are available on the market today. Essentially these are foaming agents, which require as little as .01 to .05 per cent to produce 400 to 600 billion bubbles in a cubic yard of concrete. This is equivalent to 4% to 6% air by volume.

2. There are two ways to entrain air in concrete--grinding up the agent with the cement clinker during manufacture, or adding the chemical at the mixer. Many factors in the concrete mix, both materials and proportions, will effect the air content for a given quantity of agent. Therefore, it is recommended for more accurate control and adjustment, to add the agent during mixing. The benefits of air-entrainment are so great, that they should be controlled accurately by batching the air-entraining agent at the mixer by an automatic dispenser.

3. Air-entraining agents impart two important qualities to concrete. The primary quality is improved durability, and resistance to alternate cycles of freezing and thawing. In addition, this entrainment of the microscopic air bubbles in the cement paste improves workability through internal lubrication, reducing the quantity of water required to produce a given consistency. The presence of so many tiny bubbles materially alters the properties of concrete in both the plastic and hardened state. Thus, while the prime function and principal benefit is to improve durability, air-entrainment also:

a. Reduces bleeding through blockage of capillaries.
b. Minimizes segregation.
c. Moderately reduces compressive and flexural strength.

d. Improves workability.

4. Each air bubble becomes a reservoir to accommodate expansion caused by the freezing of free water within the concrete. As the free water within the capillaries freezes, the expansive pressure is relieved when the excess water is forced into the entrained air voids. This permits expansion during freezing without damaging the concrete. When the concrete thaws, the air compressed in the bubbles forces the water back into the capillaries. Thus the bubbles perform their function during repeated cycles of freezing and thawing. This extends the serviceable life of concrete while reducing maintenance costs significantly. It has been conclusively shown that concrete with air entrainment will withstand hundreds cycles of freezing and thawing; whereas regular concrete without air entrainment, may fail after only a small number of cycles.

5. The solid ingredients in concrete have high coefficients of friction. Angular aggregate particles provide poor lubrication. These mixes rely on the cement-water paste for lubrication. Much more water is required in concrete mixtures for lubrication than can combine chemically with the cement. The quantity of water that may be added for lubrication is limited because of the adverse effects of too much water on the strength and durability of the hardened concrete. Entrained air however is a good lubricant. The bubbles act as ball bearings throughout the mortar in sizes similar to fine sand particles. These air bubbles have complete flexibility of shape, thus reducing internal friction. This permits the paste to function as it is intended -- to bind the aggregates into a strong dense mass, which is concrete. Thus entrained air reduces the need for excess water, increasing the strength of the paste, by reducing the W/C ratio. It also reduces the basic porosity (capillary structure within the mass) minimizing the possibility for migration of water into and out of the hardened concrete, increasing the resistance to frost and chemical attack. Air entrainment performs this function far better than any other method. The relationship between density and air entrainment becomes clear when the air bubbles are recognized as discontinuous particles of an extra fine aggregate, which reduce the small channels and capillaries in the hardened concrete.

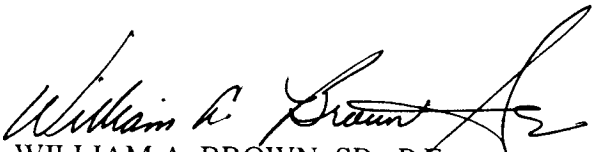
6. While improving durability and workability, air entrainment will result in moderate strength reduction. If no adjustments are made to the design mix to account for the air, there will be approximately a 5% reduction in compressive strength for each 1% of entrained air. If the mix is adjusted with proper reductions in mixing water and fine aggregate because of the increased workability and absolute volume, the strength losses will be slight. Usually the design mix includes an allowance for entrained air. Lean mixes (low cement content) may actually increase strength with entrained air.

7. There are three ASTM methods for testing the air content of fresh concrete: (a) The gravimetric method, ASTM C 138; (b) The volumetric method, ASTM C 173; (c) The pressure method, ASTM C 231. The latter method is the easiest and thus the one most commonly used for field testing. It is the method specified for normal weight concrete in all of the Corps Guide Specs. For light weight concrete the volumetric method, ASTM C 173 is used. Tests for air

content should be made repeatedly during placement, and the quantity of air entraining admixture should be adjusted based on these tests. Each of the referenced specifications gives a range of required air content in percent by volume, which varies slightly with the size of the coarse aggregate. The specifications also require the test results to be recorded on control charts, be available to the government at all times, and be submitted weekly. It includes the allowable deviation from the specified range of air content, and the required consistency of each air content test as compared to previous tests. The information, and format of these charts is detailed in the specifications.

8. Standard precautions used with normal concrete should be used for air entrained concrete. Also the design mix should be adjusted for the entrained air. Since the bubbles serve essentially as a fine aggregate, the fine aggregate should be reduced by approximately an equal volume of entrained air. The cohesive nature of air entrained concrete requires that it be carefully vibrated to remove entrapped air. Entrained air is not seriously affected by proper vibration. The bubbles are so fine that they do not combine to form larger ones. In fact, they lubricate the concrete allowing the entrapped air to more easily escape. However, over vibration can reduce the air to unacceptable limits.

9. This DCAF has been coordinated with the following HQUSACE organizations: Engineering Division(CEMP-ET); Operations, Construction and Readiness Division(CECW-OC); Engineering Division(CECW-EG). POC for this DCAF is C. J. Harris, CEMP-CE. Telephone: (202) 761-8801.



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